SPEED OF COMPREHENDING SUBMARINE FIRE CONTROL DISPLAYS: II. FURTHER EVIDENCE OF RIGHT-LEFT DIFFERENCES

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SUMMARY PAGE

THE PROBLEM

To examine man's ability to make quick decisions based on displays containing information about "right" and "left".

FINDINGS

Subjects took longer to interpret displays involving the direction left than displays involving right in two extensions of previous research. How these asymmetries emerged depended in part on the details of subjects' strategies in interpreting and responding to complex displays.

APPLICATION

These studies provide evidence of limitations of man's ability to think about space. Such limitations are relevant to tasks like submarine fire control or navigation, where indirect information must be used to derive spatial representations. Further, since tasks similar to these reported have been used as indices of performance in hyperbaric environments, the kind of analysis provided here could prove useful in pinpointing the nature of performance deficits in such environments.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit MF51.524.004-2002DX5G. It is number 4 on this particular research work unit. It is the second in a series on processing displays. The first in the series was NSMRL report 725 published in August 1972. The present report was submitted for review on 19 June 1973, approved for publication on 14 September 1973 and designated as NSMRL Report No. 758.

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ABSTRACT

Two experiments present further confirmatory evidence that the mental representation of the term "right" is simpler than that of "left." Experiment I was a simple extension of a series of earlier experiments, and showed that printing words top-to-bottom in displays did not eliminate the asymmetry in reaction times between "true" matches for "right" and for "left". This further confirms that the asymmetry depends upon mentally representing the two directions rather than upon visual scanning habits. Experiment II examined the verification of displays containing sentences and pictures. This more complex task induced greater variability among subjects, presumably because they adopted different strategies. Nonetheless, the confirmation of a strategy-free prediction provided additional support for the claim that "right" is easier to comprehend than "left."

SPEED OF COMPREHENDING SUBMARINE FIRE CONTROL DISPLAYS: II. FURTHER EVIDENCE OF RIGHT-LEFT DIFFERENCES

INTRODUCTION

An earlier report summarized a series of preliminary investigations which suggested that right-handed men have more trouble understanding the direction left than the direction right.[1] This difference emerged during the central information processing involved in making a decision based on information in a visual display, not during the scanning of the display. This kind of cognitive limitation could have profound significance for operational tasks like navigation or fire control, where inferences about positions and motions in space must be made from very indirect evidence. At least two further lines of research need to be pursued in light of these preliminary findings. First, since the studies in the earlier report used simple laboratory tasks in order to verify the cognitive limitation in a clear-cut way, it will be important to assess whether tasks related to those used at sea are affected in a similar fashion. A series of investigations using tactical line-of-sight diagrams from submarine fire control operations is currently in progress and will be reported upon in the near future. A second line to explore is how reliable or robust the effects are when extended to other situations or tasks. The two experiments reported here relate to this second objective.

Experiment I

Olson and Laxar[1] were able to argue on the basis of their studies that the relatively greater difficulty encountered in understanding the direction left was not due to an interaction between previously acquired reading or scanning biases and the particular displays used in that research. The present experiment provides a further demonstration of this point. The displays used in the previous research were altered so that the printing ran from top-to-bottom rather than from left-to-right, providing at least a partial de-correlation of peripheral scanning and processing relevant to our hypothesis. It is unlikely that simply printing words vertically totally eliminates left-to-right scanning biases, so this manipulation is probably weaker than those reported before. Nonetheless, our prediction is that the asymmetries due to right and left still ought to emerge in the form of faster reaction times for "true" displays containing the term <u>right</u>. A voice key response was used instead of a button press to ameliorate the strong S-R compatibility effects found in the earlier studies.

METHOD

The four displays used were similar to those in the earlier studies, except that now the words were printed vertically instead of horizontally as shown in Figure 1. These were shown to <u>Ss</u> in a Scientific Prototype three-field tachistoscope. The width of the displays from one dot position to the other subtended a visual angle of 4° at a distance of 1092 cm. As a notational

convention, *right* and *left* will refer to the word in the center of each display, RIGHT and LEFT to the side on which the black dot appeared. The displays *right*-RIGHT and *left*-LEFT were the "true" conditions, since the word correctly named the side on which the dot appeared. The other two displays were the "false" conditions.

The displays were presented to *S*s in blocks of 28 trials, each display appearing seven times a block. The first four trials in a block were warm-ups and were not analyzed. Each *S* was given four blocks of trials for a total of 96 experimental trials plus 16 warm-ups, all within a single 45-minute session. The order of presentation within each block was independently randomized for each *S* and each block.

S sat in a special experimental booth which contained the viewer for the tachistoscope, a panel at desk top height immediately below the viewing port containing the start button, and the microphone for a Grason-Stadler E7300A voice-operated relay. *S* initiated each trial by pressing the start button with one of his forefingers. One second after he pushed the start button one of the four displays flashed on and he responded "true" or "false"

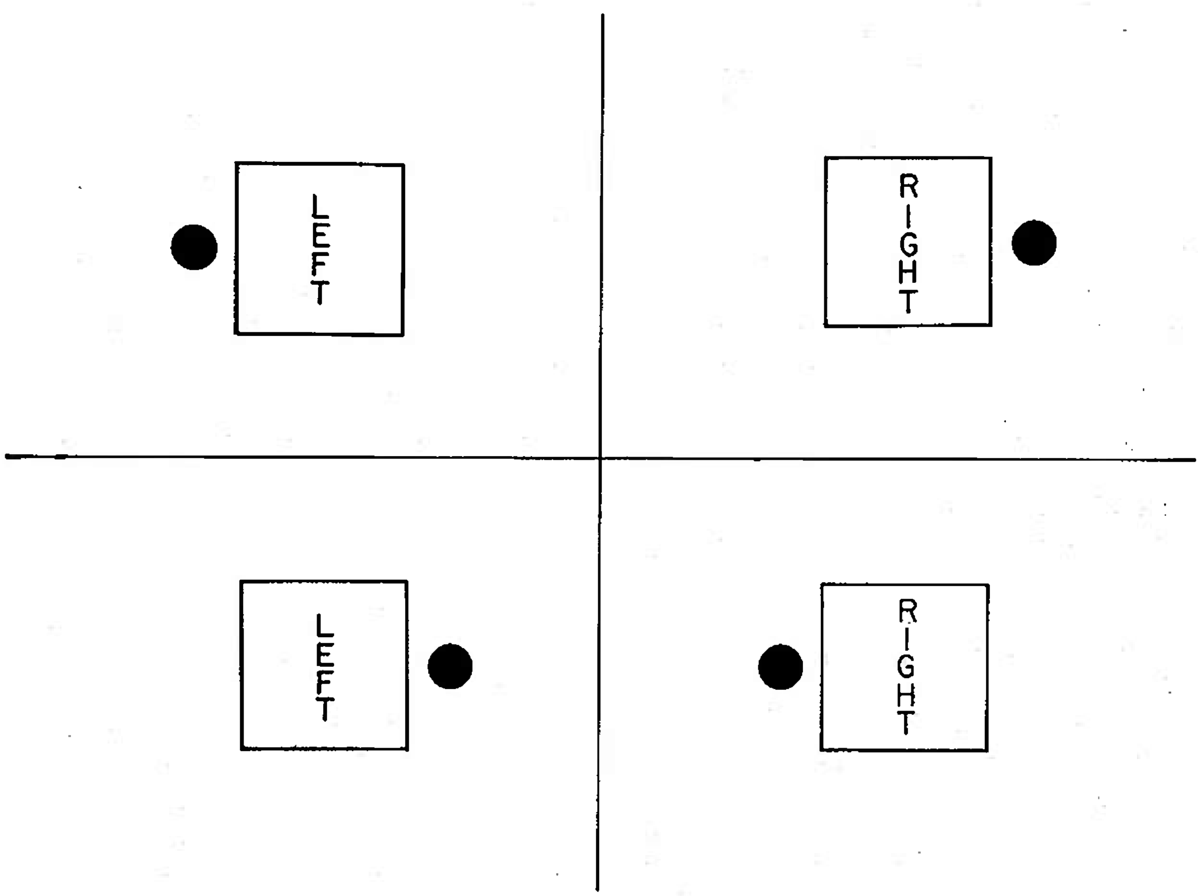

Fig. 1. Displays used in Experiment I.

by saying the word as quickly as possible. Virtually no trials were lost due to false starts, stuttering, or other difficulties associated with the use of the voice key. A fixation point was used to direct S to look at the word first. On each trial the S was informed of his reaction time and told whether or not he was correct. Reaction times were measured from the onset of the display to the S's verbal response, and were recorded to the nearest hundredth of a second. A preliminary study of the voice responses showed that "false" was produced 20 msec. faster than "true" (See Appendix A for details). Ss were 14 right-handed Naval enlisted men.

RESULTS

Mean latencies were computed for correct responses only for each block by display by S combination, yielding 16 means for each S, or 224 overall. The overall mean latencies and error rates for the four displays collapsed over blocks are shown in Figure 2.

A repeated measures analysis of variance of the 224 means for the effects of stimulus word (right-left), dot position (RIGHT-LEFT), and test block (1 through 4) revealed the following significant effects: (1) displays with right yielded marginally faster reaction times than those with left, $F(1,13)=4.45$, $.05<p<.10$; (2) displays with RIGHT were processed more quickly than those with LEFT, $F(1,13)=7.49$, $p<.025$; (3) Ss became faster over blocks, $F(3,39)=5.24$, $p<.05$; and (4) there was a reliable right-left by RIGHT-LEFT interaction, meaning that "true" displays were responded to more quickly than "false" ones, $F(1,13)=6.62$, $p<.025$. Analysis of errors revealed that only the interactions of right-left and RIGHT-LEFT ($F(1,13)=4.79$, $p<.05$) and RIGHT-LEFT with blocks of trials ($F(3,13)=3.25$, $p<.05$) were significant.

DISCUSSION

Although the effect is not as strong in this experiment as it was in the earlier series, the right-RIGHT display is responded to more quickly than any of the other three, consistent with the theoretical position outlined in the previous report[1]. Thus, altering the orientation of the printing in the displays and changing to a voice key response does not eliminate the cognitive asymmetry between the terms "left" and "right" although for some unknown reason it does appear to attenuate it.

Experiment II

Do these effects only emerge with the very simple kind of displays used in the earlier research, or can similar asymmetries be found in more complex tasks? The present experiment provides data for one of a series of extensions into more complex tasks.

The current investigation involved the ability of subjects to make true-false verification responses to displays consisting of a sentence and a drawing of two geometrical shapes. When the sentence correctly described the picture subjects were to respond "true", otherwise "false". This paradigm has been extensively used for investigations of a variety of psycholinguistic and cognitive phenomena, including the

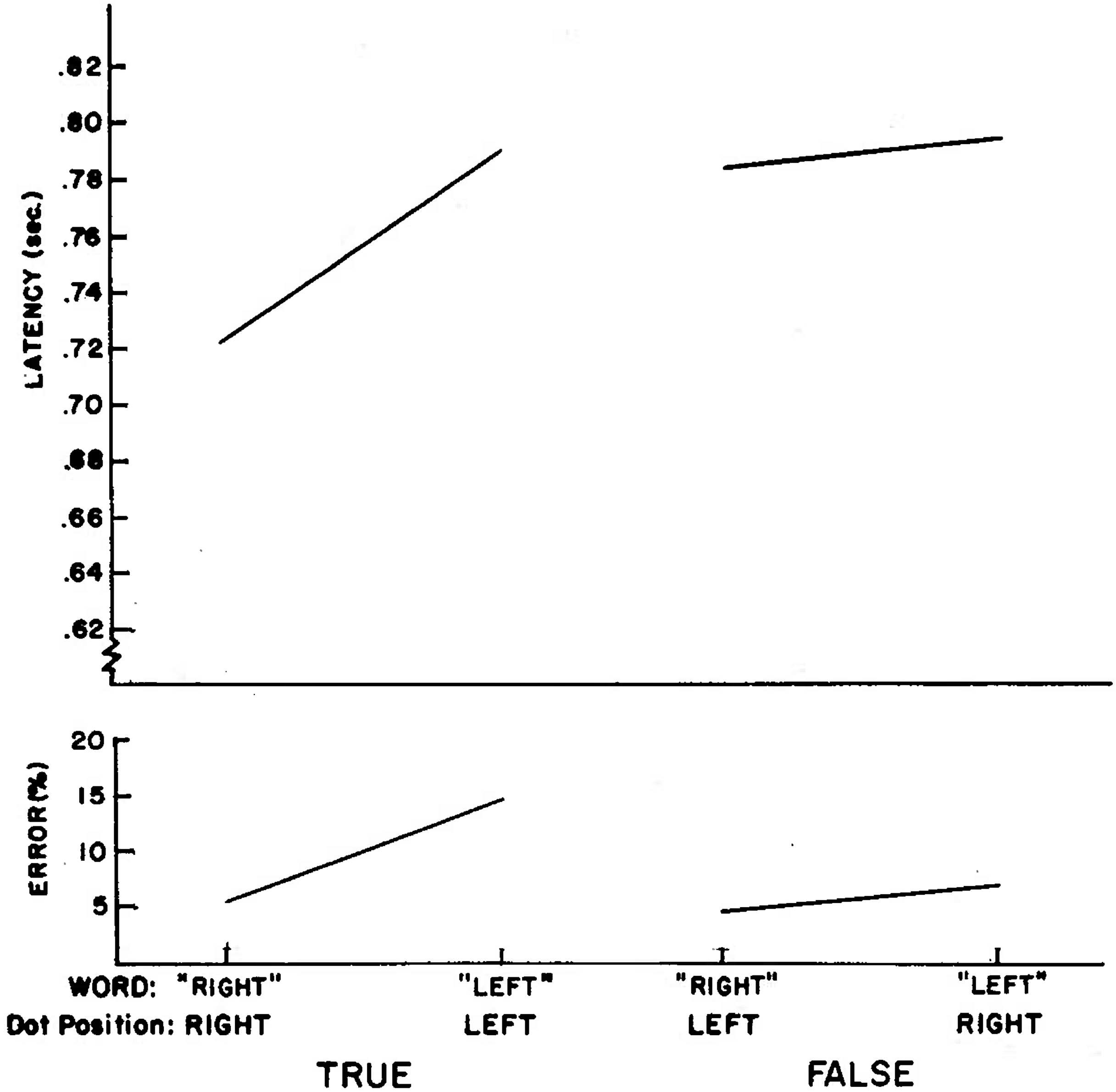

Fig. 2. Mean reaction times for correct responses and error percentages for Experiment I.

properties of individual lexical items or concepts appearing in the sentences.[2,3,4,5,6,7,8] Thus, in using this paradigm we draw upon theoretical and methodological logic which has an extensive literature.

METHOD

Sixteen displays were created by using all combinations of four factors each having two levels in the frame The X is (not to the $\left\{\frac{\textit{Right}}{\textit{Left}}\right\}$ of the Y. The

factors varied were: (a) subject of sentence ("triangle" or "circle"), (b) spatial term (left or right), (c) affirmative or negative sentence, and (d) arrangement of the objects in the picture (circle-triangle or triangle-circle). Four sample displays are shown in Figure 3.

The displays were printed on cards for use in a three-field tachistoscope. The longest sentences subtended a visual angle of 4° at 1092 cm. A deck of 160 cards was prepared for each S from computer-generated sequences of trials. Each S saw the sixteen different displays ten times in the experiment. Each display appeared once in each successive block of sixteen trials. Order within each block was randomized independently, with the constraint that at the block-to-block transitions a particular display was not repeated within three trials of itself. A new sequence was created for each S.

S sat in the same experimental booth as in Experiment I. The response

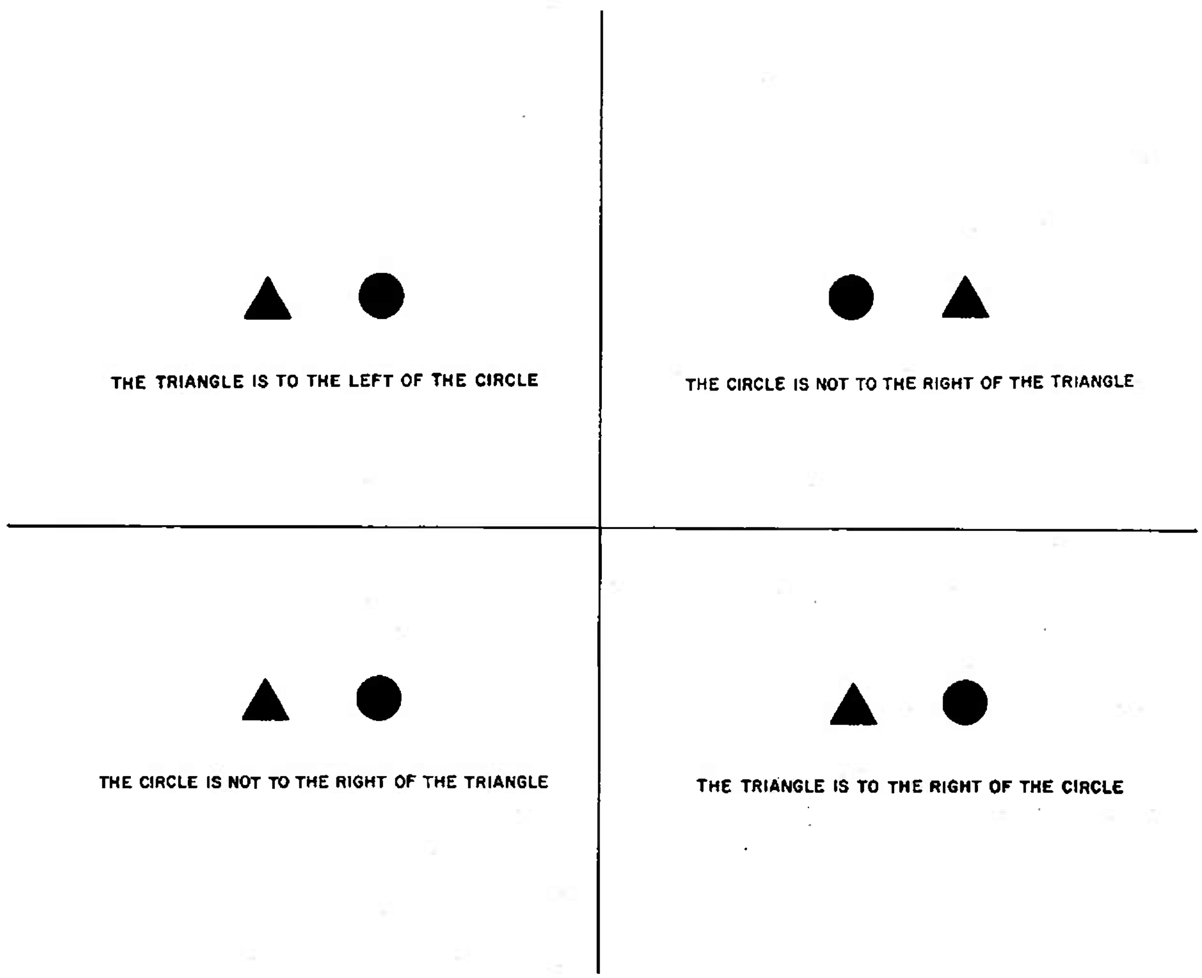

Fig. 3. Examples of displays used in Experiment II.

panel contained keys for "true" and "false" responses with the start button centered above the keys. S initiated each trial by pressing the start button with one of his middle fingers while his forefingers were positioned on the two response keys. The position of the "true" key was counterbalanced across Ss. One second after S pushed the start button one of the sixteen displays flashed on and he responded "true" or "false" as quickly as possible by pressing one of the keys. A fixation point was used to direct the S's attention to the center of each display, but no special instructions were given regarding the order in which the sentence and picture ought to be processed. On each trial the S was informed of his reaction time and told whether or not he was correct. Reaction times were recorded to the nearest hundredth of a second.

The 160-trial sequence was run in a single session, with a short break about half way through the sequence. During the instructions S was given from four to eight displays as practice, and as a check on his understanding of the task. The remaining eight to twelve displays from the set of sixteen were shown before the 160-trial sequence, with no interruption between these warm-ups and the experimental sequence. Data from the warm-up trials were not analyzed. The Ss were 23 Naval enlisted men, all right-handed.

RESULTS

Mean latencies were computed for correct responses only for each display-type, collapsing over the two symmetrical versions of the material created by altering the order of the pictured objects. Thus, each S has eight mean latencies (true-false by affirmative-negative by right-left) which were used in the analysis. The overall mean latencies and the error rates for the eight conditions are shown in Figures 4 and 5.

A repeated measures analysis of variance was done on the 184 means (eight conditions by 23 subjects) for the effects of (a) affirmative-negative (b) true-false and (c) right-left. The results of this analysis are shown in Table 1. The analysis of correct reaction times revealed that on the average Ss were 142 msec faster on true displays than on false ones, 812 msec faster on affirmative displays than on negative ones, and a marginally significant 92 msec faster on right displays than on left ones. The significant T x A interaction is due to the difference between true-false displays being greater for affirmatives than for negatives. Finally, the theoretically important triple interaction has a complex interpretation which can best be spelled out in a subsequent discussion about the patterns of reaction times that would emerge for two different processing strategies.

An analogous analysis of errors revealed the following significant effects: (a) more errors were made on negative sentences than on affirmative ones, $F(1,22) = 8.32$, $p < .01$; (b) there was an interaction between true-false and right-left, $F(1,22) = 4.83$, $p < .05$. The triple interaction of T x A x R approached significance,

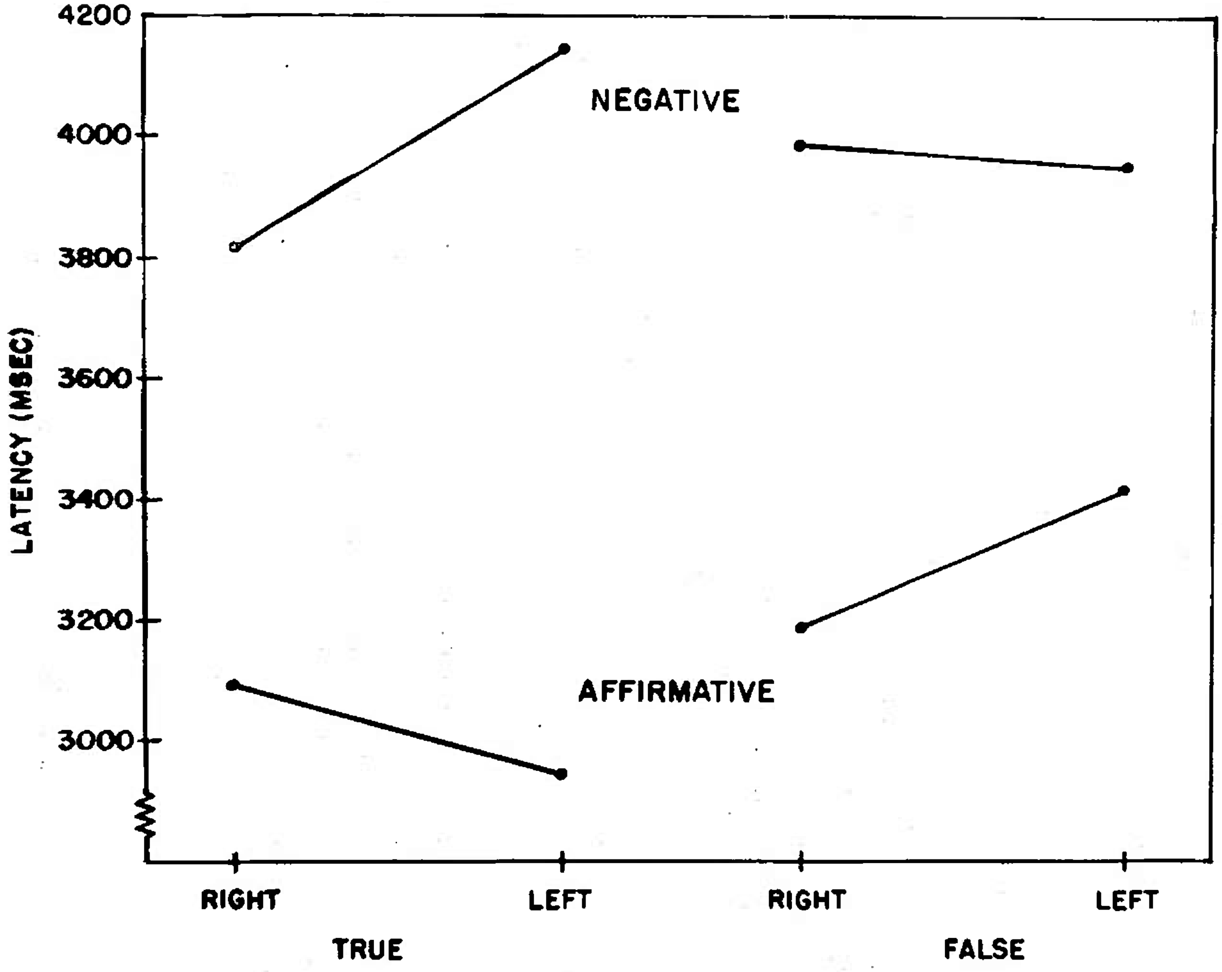

Fig. 4. Mean reaction times for correct responses in Experiment II.

$\underline{F}(1,22) = 3.83$, $.05 < \underline{p} < .10$. The important fact revealed by the data in Figure 5 is that in general the error rates were in the same direction as the reaction times, especially with respect to the left-right differences of central interest to this report. Since reaction time is the primary dependent variable in this research, no further mention of error rates will be made.

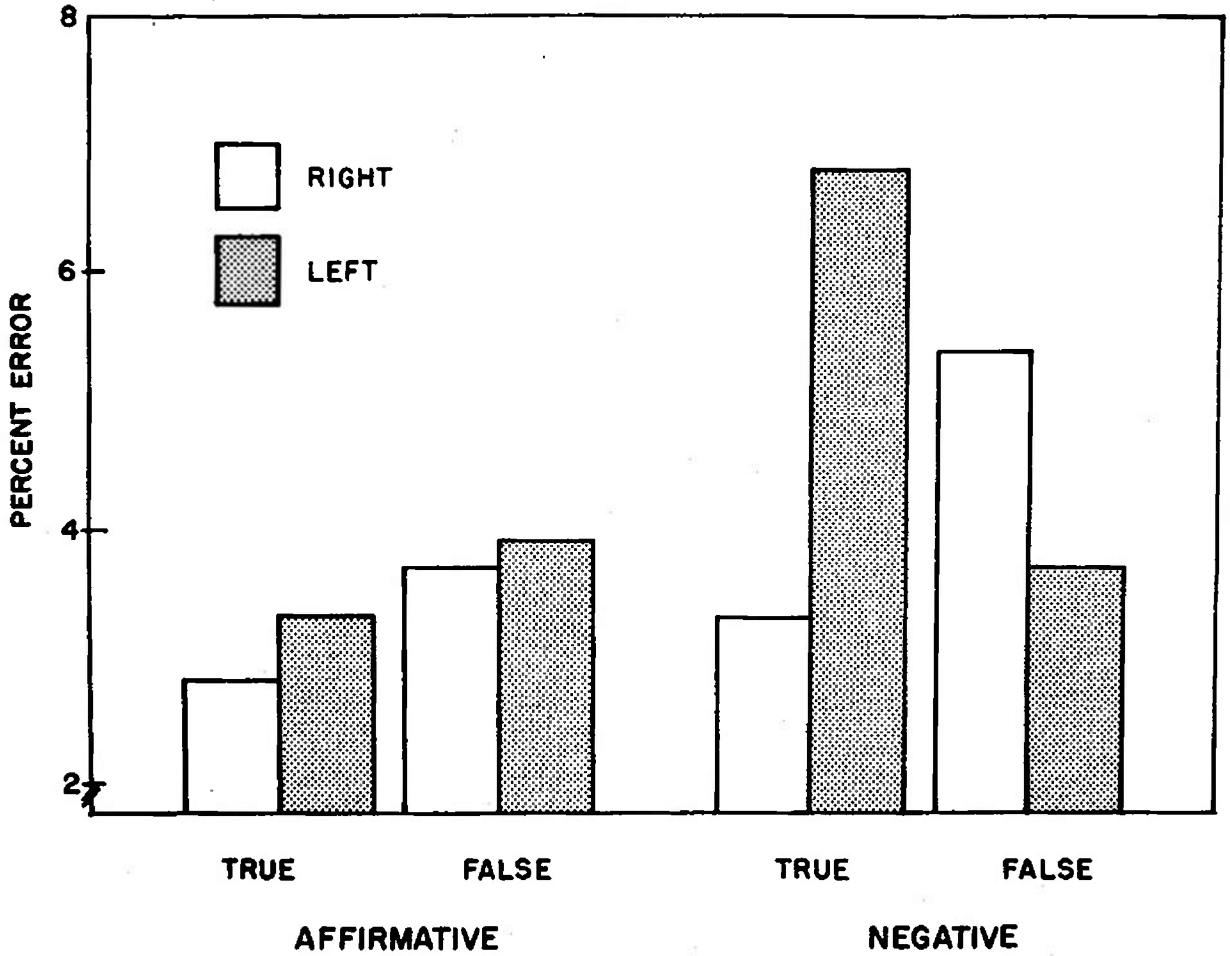

Fig. 5. Error percentages for Experiment II.

Table 1. Summary of Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	$\underline{F}$	$\underline{p}$
True-False (T)	1	0.96947	13.19	<.005
Affirmative-Negative (A)	1	30.69306	134.87	<.0005
T x A	1	0.85272	10.03	<.005
Right-Left (R)	1	0.36454	3.67	$.05<\underline{p}<.10$
T x R	1	0.00001	---	---
A x R	1	0.07997	2.23	>.10
T x A x R	1	1.46031	21.09	<.0005
Subjects (S)	22	8.30517		
T x S	22	0.07352		
A x S	22	0.22757		
T x A x S	22	0.08505		
R x S	22	0.09921		
T x R x S	22	0.05064		
A x R x S	22	0.03582		
T x A x R x S	22	0.06922		

DISCUSSION

The best way to interpret the complex effects in these data is to examine them with the help of two models of how Ss might be processing the displays. That it is necessary to consider variations in strategy is evident from Figure 6, which shows the patterns of correct reaction times for individual Ss. To the extent that the pattern of times reflects the Ss' processing, it is clear from Figure 6 that there was much between-S heterogeneity.

The two models are derived from processing assumptions most completely described by Clark and Chase[2,3] and Trabasso[4,5]. The basic idea of these models is that the total time taken to respond to a given display can be decomposed into theoretically interesting parts. Under the strongest form of this model, it is assumed that the subjects go through a series of stages and accumulate additional time for various operations at each of these stages. Thus, the components of the reaction time due to various factors are assumed to be additive.

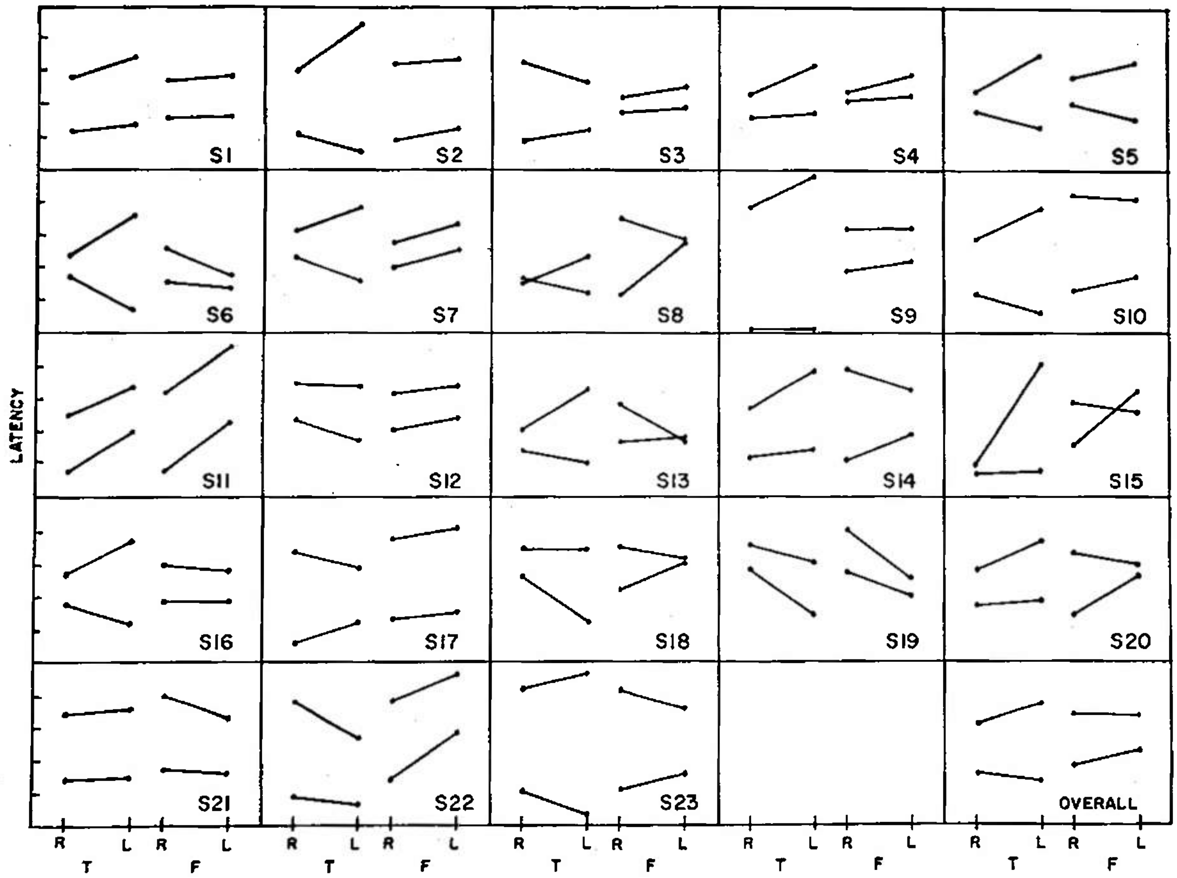

Fig. 6. Mean reaction times for correct responses for individual subjects in Experiment II (Ordinate marked in 500 msec intervals, but in relative rather than absolute time).

Let us use the framework developed by Chase and Clark to specify the two strategy-dependent variants on processing that we are interested in. They have proposed that the S's task can be broken down into four stages: (a) sentence encoding, (b) picture encoding, (c) sentence-picture matching, and (d) response production. The order of (c) and (d) is of course fixed, but subjects are free to code the sentence and the picture in any order, and this makes a big difference in the pattern of reaction times one would predict.

No specific instructions were given about what kind of strategy to use in verifying the displays, though on the basis of prior research[2,3] strategy differences have produced striking effects in the patterns of reaction times. We will discuss two models based on two different logical strategies, and show how certain predictions regarding the asymmetry of right and left hold regardless of which strategy might be used. These strategy-free predictions will offer the strongest test of our hypothesis.

We can illustrate how such models work by examining the sentence-first version that would hold for the present paradigm. The two encoding stages are necessary because in order for a comparison to be made between the sentence and the picture they must be translated into some common mental format. What the exact nature of the format might be, that is, whether it is linguistic, imaginal, conceptual, or something else, is unimportant for now. What is important is that the format preserve the logical, functional relationships among the elements of the sentences and pictures that we will now specify.

We will start with the easiest examples, those of affirmative sentences like The circle is to the left of the triangle. Let us represent the core meaning of this statement in the following notation: left (circle, triangle) or L(C,T). This notation translates the spatial term left into a two place function, with the first argument representing the variable object and the second argument the standard. That is, the location of the circle is being represented with respect to the supposedly known location of the triangle. Given this example, the representation of all possible affirmative sentences in the present experiment is straightforward.

Negative sentences introduce only one new wrinkle. We assume that negation functions as an embedding proposition for sentences like The circle is not to the left of the triangle, such that we could accurately paraphrase this sentence with It is false that the circle is to the left of the triangle. The simple affirmative statement, The circle is to the left of the triangle, is embedded in the frame, It is false that P. We can represent this in our notation as false that (left(circle, triangle), or more economically, F(L(C,T). That this is a reasonable characterization of explicit sentence negation can be verified on the basis of linguistic[9] and psychological data.[10]

In the sentence-first model, it is assumed that the S encodes the picture in relation to how he encoded the sentence. Basically, it is assumed that the S encodes the picture as an affirmative proposition with the same spatial term as the sentence. Thus, if the subject saw a display with the sentence The circle is to the left of the triangle and the picture of a circle on the left and a triangle on the right, he would end up with the following representations:

sentence	L(C,T)
picture	L(C,T)

They are, of course, identical, since given the constraints on coding pictures in this strategy the sentence is a direct reflection of the code of the picture. Other cases are more complex. The complete set of sentence-picture codings for the sentence-first strategy is shown in Table 2.

Once the S has these two representations, he compares them in order to derive a "true" or "false" response by following the algorithm shown in Figure 7. The S uses a truth index to keep track of the truth value associated with the comparison. This index is initially set at true. First the S compares the

Table 2. Model for the Sentence-First Strategy

	Sentence	Picture	Latency Components
True Affirmative	R(C,T) R(T,C)	R(C,T) R(T,C)	t
	L(C,T) L(T,C)	L(C,T) L(T,C)	t + a
False Affirmative	R(C,T) R(T,C)	R(T,C) R(C,T)	t + b
	L(C,T) L(T,C)	L(T,C) L(C,T)	t + a + b
True Negative	F(R(C,T)) F(R(T,C))	R(T,C) R(C,T)	t + b + (c + d)
	F(L(C,T)) F(L(T,C))	L(T,C) L(C,T)	t + a + b + (c + d)
False Negative	F(R(C,T)) F(R(T,C))	R(C,T) R(T,C)	t + (c + d)
	F(L(C,T)) F(L(T,C))	L(C,T) L(T,C)	t + a + (c + d)

inner strings, and if they mismatch reverses the truth index. Then he compares the outer or embedding strings (the one which encodes negation), and again if a mismatch is found between the outer strings the value of the truth index is reversed. Following this algorithm through for each of the possible sentence-picture encodings shown in Table 2 reveals that the correct response results in each instance if the final value of the truth index is used for responding. For example, with the true negative, the subject first finds a mismatch between the inner strings and changes the truth index from true to false. But the outer strings also mismatch, so the value is changed from false back to true.

Time is accrued in the following ways. First, on the assumption that left is more difficult than right, it takes time _a_ longer to encode sentences with _left_. Second, it is assumed that it takes time _c_ longer to encode a negative than an affirmative sentence. Third, whenever the inner

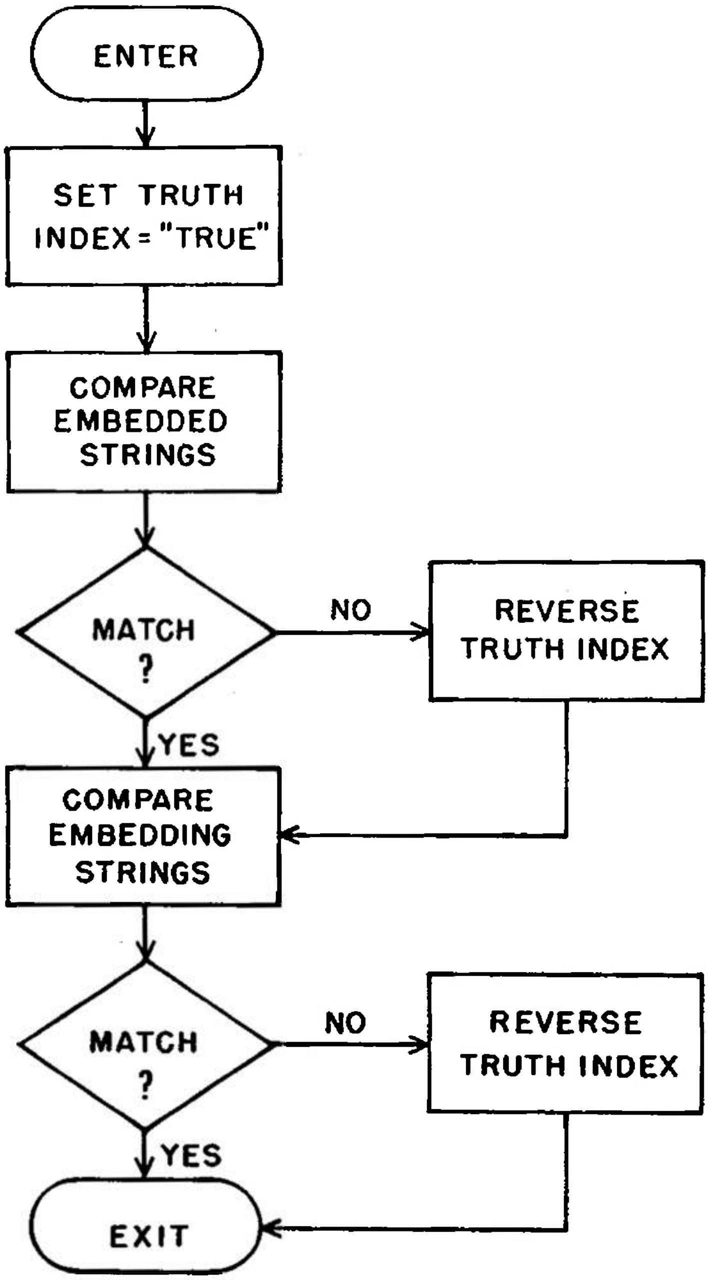

Fig. 7. Comparison algorithm for the sentence-first strategy.

strings mismatch it takes time b to reverse the truth index. Finally, whenever the outer strings mismatch it takes time d to change the truth index. These components are shown in algebraic form for the various sentence-picture combinations in the right-hand column of Table 2. The parameter t summarizes the time it takes for all the operations which are assumed to be common for all the displays.

At first glance it might seem that the theoretical analysis just sketched differs from that presented in our earlier report[1] and implicit in our discussion of Experiment I. However, there is a relatively straightforward correspondence between the models for the two different kinds of displays. In order to make the comparison easier Table 3 reproduces the relevant information from the earlier report. The model in Table 3 adds the following increments to the baseline time as a function of display characteristics: an amount a when the word is left, an amount b when the dot is on the LEFT, and an amount c when the correct response for the display is "false." All of these features are in the model in Table 2 although in somewhat different form. The sentence-first strategy just outlined confounds the encoding times for left and LEFT, since S is always assumed to encode the picture with the same spatial term found in the sentence. Thus, the parameter a in Table 2 in reality corresponds to the parameters a + b in Table 3. The parameter c in Table 3 corresponds to the inner string mismatch process illustrated in Figure 7, so c in Table 3 corresponds to b in Table 2. The parameters c and d in Table 2 arise solely from the negation present in the more complex displays of Experiment II and are not present in the simpler model. We use the analysis in Table 2 because this is how other investigators[2,3,4,5] have presented analogous models. But it is important to realize that no difference of theoretical logic has been introduced over the earlier analysis.

The picture-first strategy does not differ in most of its details from the sentence-first one, except that the pictures have a different representation. In fact, it is assumed that the S always encodes the pictures in the same way: as an affirmative sentence with the object on the left as subject and with the predicate left-of. Thus, there are only two possible picture encodings, L(T,C) and L(C,T). This is the most logical consistent encoding of the picture, given the general tendency of subjects to scan the display from left-to-right. This scanning bias is of course accentuated by having the Ss reading a sentence from left-to-right in the same displays. Sentences are encoded just as before. The complete set of sentence-picture encodings are shown in Table 4.

One slight change is introduced in the algorithm the S follows in determining whether to respond true or false. The S must first check whether or not the predicate is the same. The sentence-first strategy guaranteed that this would be the case, since picture encoding depended upon sentence coding. But since that is not the case with the

Table 3. Summary of Experimental Conditions and Additive Reaction Time Model for Simple Displays Like Those in Experiment I

Condition	Reaction Time Components
right/RIGHT	t
left/LEFT	t + a + b
right/LEFT	t + b + c
left/RIGHT	t + a + c

t = baseline time

a = left encoding time

b = LEFT encoding time

c = falsification time

picture-first strategy, it happens that half the time the predicates mismatch. Thus, Ss finding such a mismatch first of all change the predicate and the order of the arguments. Once they have done this they follow the algorithm outlined in Figure 7. The complete picture-first algorithm is shown in Figure 8.

The latency components are essentially the same, except that we now add a parameter e for the time taken to change the predicate. Furthermore, since all pictures are encoded as LEFT, the LEFT encoding increment is now part of the baseline time t' while a' represents only left encoding. The complete set of latency components are shown in Table 4.

To see the effect of possible right-left differences on the predicted pattern of latencies, the predictions of the two strategies are shown graphically in Figure 9. The dashed lines show how the times would look if there were no right-left differences, while the solid lines show roughly what would happen to each of the set of predictions if a right-left difference were superimposed. The main effect to notice is that with both strategies the right-left difference has the same effect on the relative ordering of the False Affirmative and True Negative times. The combined effects for True Affirmative and False Negative depend on the exact magnitude of the right-left difference, but in general the right-left effects for these two tend to

Table 4. Model for the Picture-First Strategy

	Sentence	Picture	Latency components
True Affirmative	R(C, T) R(T, C)	L(T, C) L(C, T)	t' + e
	L(C, T) L(T, C)	L(C, T) L(T, C)	t' + a'
False Affirmative	R(C, T) R(T, C)	L(C, T) L(T, C)	t' + b
	L(C, T) L(T, C)	L(T, C) L(C, T)	t + a' + b + e
True Negative	F(R(C, T)) F(R(T, C))	L(C, T) L(T, C)	t' + b + c + d
	F(L(C, T)) F(L(T, C))	L(T, C) L(C, T)	t' + a' + b + c + d + e
False Negative	F(R(C, T)) F(R(T, C))	L(T, C) L(C, T)	t' + c + d + e
	F(L(C, T)) F(L(T, C))	L(C, T) L(T, C)	t' + a' + c + d

go in opposite directions. Thus, on the assumption that the data for a group of Ss contains a mixture of the two strategies just outlined, if right is simpler than left, a clear, significant right-left difference should emerge for False Affirmatives and True Negatives.

The data in Figure 2 show that this is the case, and statistical evaluation of the three-way interaction shows that the difference between right and left is much greater for True Negatives and False Affirmatives than for True Affirmatives and False Negatives (the

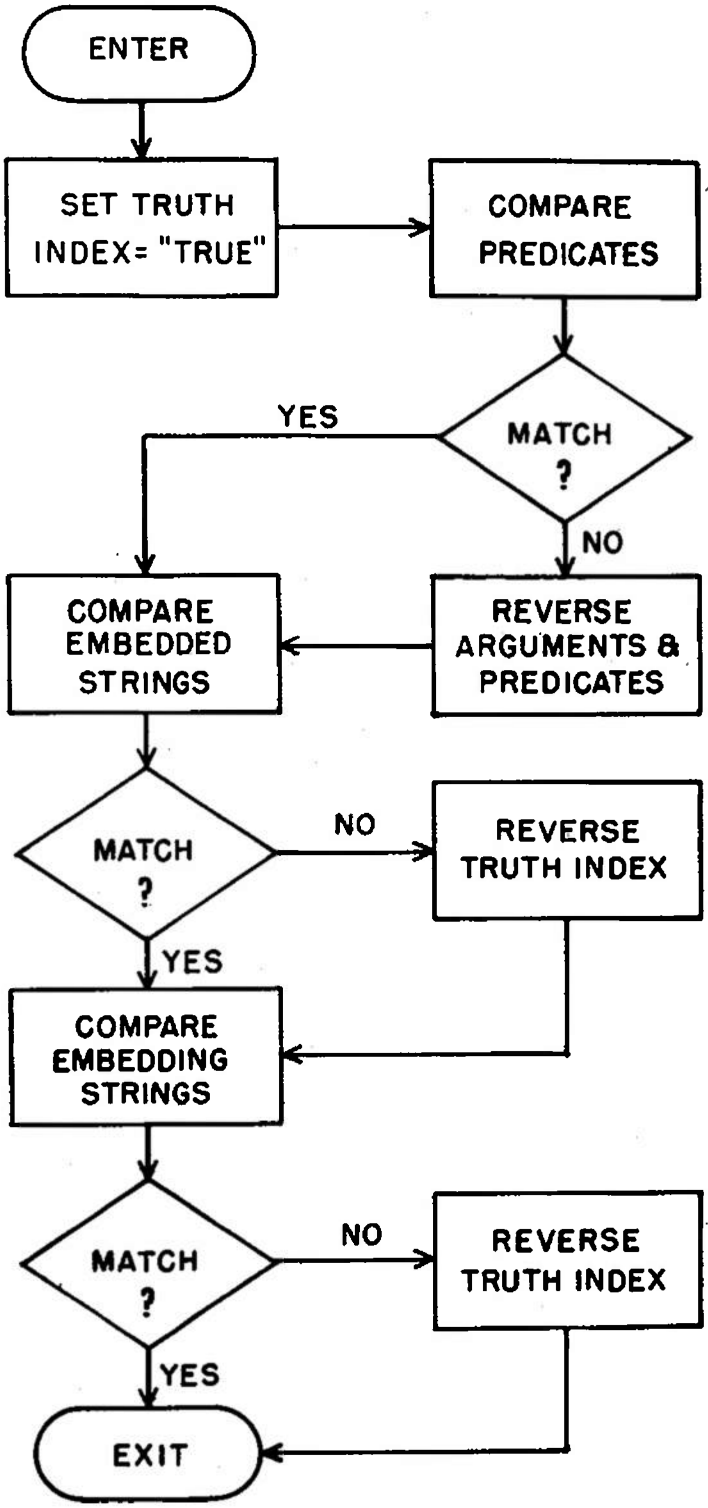

Fig. 8. Comparison algorithm for the picture-first strategy.

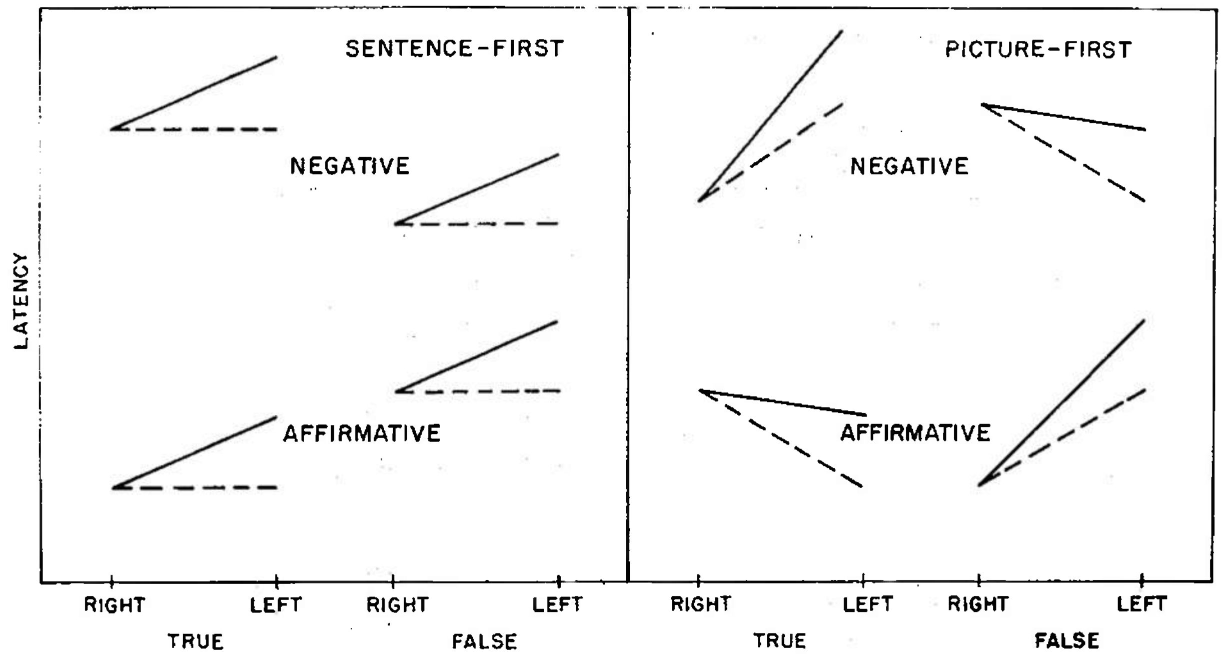

Fig. 9. Effect of right-left asymmetry on hypothetical data for the two models (Dashed line is for case with no asymmetry, solid line shows it with asymmetry.).

value of the contrast exceeded the critical value for the Scheffe procedure at $p<.025$). Thus, in the two critical cases where both strategies make the same prediction, the right-left difference is statistically reliable.

In order to get a general idea of the plausibility of our interpretation that the group data represent a pooling of individuals using different strategies, parameters for the models shown in Tables 2 and 4 were estimated. Several assumptions were made. First, we assumed that half the Ss used each strategy. This is clearly an ad hoc assumption, although the a posteriori evidence in Figure 6 seems to suggest about an equal mix of strategies. Second, in order to get fewer parameters than degrees of freedom it was assumed that all parameters in common between the picture-first and sentence-first strategies were the same. Further, t and t' were collapsed into one parameter, as were a and a'. This leaves us with five parameters to estimate with eight data points: t, a, b, $(c+d)$ shared by the two models, and e unique to the picture-first model.

Table 5 shows the predictions for this case where equal numbers of subjects are using each strategy. This was the model that was fit to the overall mean data of Figure 2. Using a least-squares procedure, the estimates for the various parameters were: $t = 2949$, $a = 94$, $b = 147$, $(c+d) = 813$, and $e = 368$. Table 5 lists the observed

reaction times along with the predictions based on these estimates. The root mean squared error[11] for these estimates is 73.3 msec, which in view of the magnitude of the parameters indicates the model does not fit the data very well. The observed and predicted values from Table 5 are plotted in Figure 10, where the main problem of the model can be seen as the failure to predict the relative intervals of the true and false data for affirmatives and negatives. The combined model in Table 5 predicts that the absolute difference between true affirmatives and false affirmatives ought to be the same as that between true negatives and false negatives (although of course the signed differences are in the opposite direction). The data clearly are inconsistent with this prediction, since the large difference between true affirmatives and false affirmatives is not mirrored for the negatives. The significant T x A interaction in Table 1 supports this. The assumptions made in order to get a reasonable number of parameters would not produce this departure from a good fit.

Table 5. Observed and Predicted Reaction Times for Experiment II (msec)

Condition	Theoretical RT Components	Observed RT	Predicted RT
True Affirmative Right	t + e/2	3092	3133
True Affirmative Left	t + a	2947	3043
False Affirmative Right	t + b	3189	3096
False Affirmative Left	t + a + b + e/2	3417	3374
True Negative Right	t + b + (c + d)	3815	3909
True Negative Left	t + a + b + (c + d) + e/2	4143	4187
False Negative Right	t + (c + d) + e/2	3986	3946
False Negative Left	t + a + (c + d)	3952	3856

Note: t = 2949
a = 94
b = 147
(c + d) = 813
e = 368

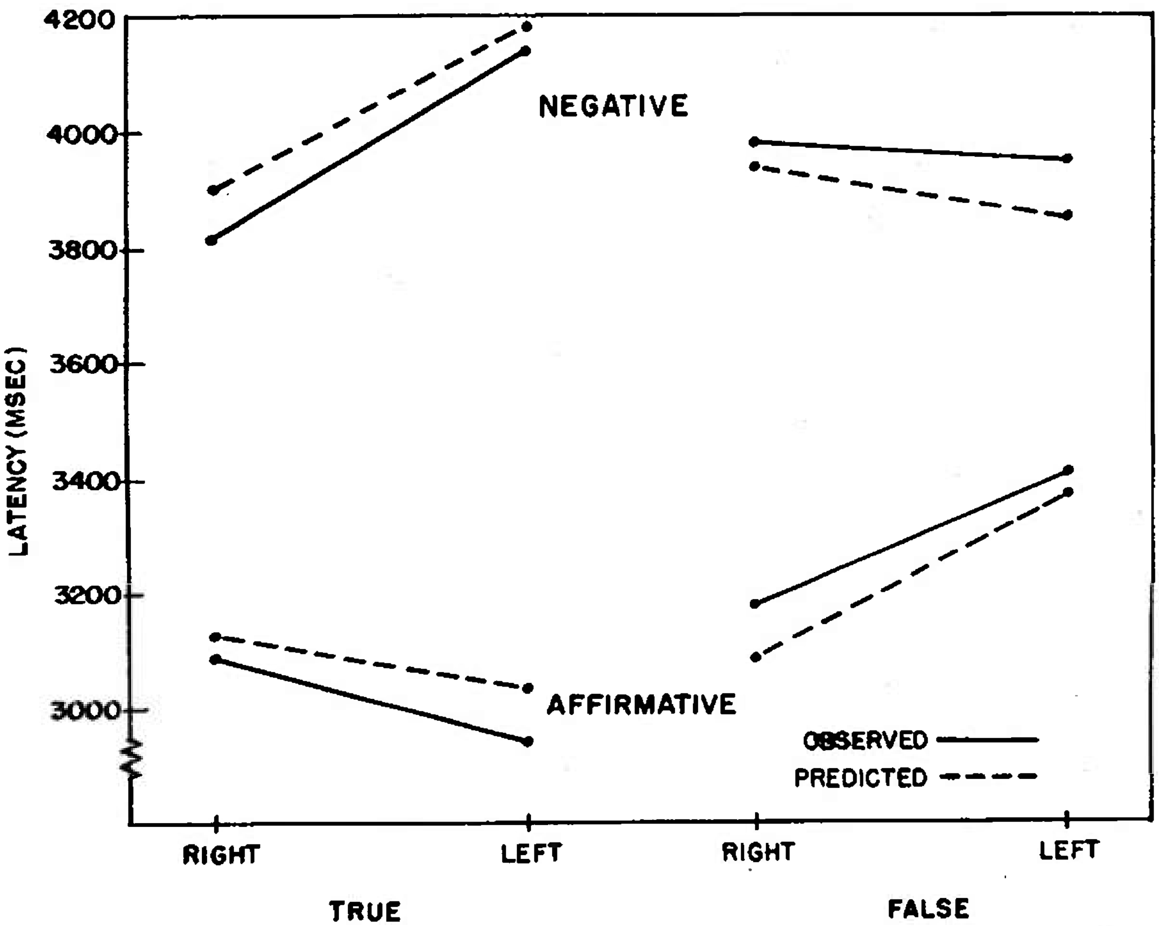

Fig. 10. Observed and predicted reaction times for Experiment II.

However, the model does quite well in accounting for the differences due to left and right. The curves in Figure 10 are remarkably parallel, confirming that the true negative and false affirmative cases are similar to each other with respect to right and left but very unlike the other two sets. Thus, while the combined model in Table 5 does not satisfactorily account for the details of the processing in this task, it does capture the right-left differences that were of primary theoretical interest.

CONCLUSION

Limitations on man's ability to perform on certain basic tasks could have profound impact on complex information processing of the kind found in submarine environments. For instance, if the kinds of asymmetries in spatial conceptualization found by Olson and Laxar[1] are reliable, it is very likely these would enter into complex, spatially oriented tasks of the kind found in

typical navigation and fire control operations. The present report provides further evidence of the reliability of the earlier findings, laying the foundation for current studies of these asymmetries in tasks using actual fire-control materials.

The particular tasks used in this and the previous investigation have yet another significance for operational contexts. Baddeley and his associates[12,13] have found that a sentence comprehension task is a very consistent and reliable index of performance decrements in hyperbaric environments, both in the chamber and at sea. We have used such tasks to partial out various component processes which might have a role in a wider range of cognitive tasks, while Baddeley and his associates have primarily been concerned with finding a broad index of performance impairment. Extensions of the kind of analysis we have used to performance in hyperbaric environments could provide an opening wedge into explicating the nature of the cognitive deficits that emerge under hyperbaric conditions.

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Appendix A

Voice Key Activation Time Differences For "true" and "false"

Several different factors might influence the exact length of the interval between a subject's decision to utter a particular word and the closing of a voice-activated relay. Some words are probably more difficult to say than others, taking more time to produce because of the particular configuration of vocal and articulatory responses involved. Similarly, for any given setting of the voice key's variable sensitivity parameters, certain speech sounds will reach the threshold of relay activation sooner than others. Finally, the specific nature of the S's task could influence the ease with which an oral response can be initiated. Only the last one of these presents a genuine methodological problem. That is, if the first two factors were to lead to a difference in the time it takes to activate the voice relay, as long as this difference was approximately constant across varying conditions of responding it could simply be taken into account as a constant measurement error of little substantive significance. Since the response words "true" and "false" are quite different phonetically and acoustically, it is important to examine both the magnitude of the latency difference in activating a voice key and the constancy of the differences under varying conditions of response.

Method. The S's task was to say either the word "true" or the word "false" as rapidly as possible in response to a display in a tachistoscope. Each S was run in four different conditions: (1) simple reaction time to the printed words TRUE and FALSE, (2) choice reaction time to the same displays, (3) simple reaction time to line drawings of a circle or a star, and (4) choice reaction time to the line drawings. Half the Ss were told to respond "true" to the star and "false" to the circle, while half were given the complementary assignment. For any given subject the assignment of "true" and "false" was the same in both the simple and choice situations. The order of the four conditions was randomized from S to S.

Each S received 30 trials on each of the four conditions. In the choice paradigms, half of the trials were assigned at random to each alternative. A new randomization was used for each set of 30 trials. A constant foreperiod of one second elapsed between the S's starting the trial with a small button and the appearance of the display in the tachistoscope. For the simple paradigm 15 trials of each stimulus were presented in a homogeneous block, with S told after 15 trials that the other stimulus would now appear. The order of the stimuli was counterbalanced across Ss. Within each block of 15 trials three different foreperiods (1, 2, and 3 sec) were used equally often, their order randomly determined anew for each block. In sum, during the choice paradigm the S always knew the foreperiod but never knew which of two stimuli would appear. In contrast, during the simple paradigm the S always knew which stimulus would

appear but did not know the length of the foreperiod.

The general procedure was quite similar to that used in Experiments I and II. S started each trial with a small button, and as soon as he responded the display disappeared. Unlike the other experiments, however, S was not told his reaction time on each trial. Further, trials on which the S made an error were rerun at the end of the session. Ss were 16 civilian and military personnel on the staff of the Submarine Medical Research Laboratory.

Results and discussion. Mean reaction times for the four experimental conditions separated for "true" and "false" responses are shown in Figure A-1. The results of a three-way within subject analysis of variance are shown in Table A-1. The analysis revealed the following significant effects: (a) "false" responses activated the voice relay an average of 20 msec. sooner than "true" responses; (b) responses to the printed words were 12 msec faster than those to the line drawings; (c) responses in the choice paradigm took 104 msec longer than those in the simple paradigm; and (d) on the basis of the W x C interaction, the difference between the simple and choice paradigms was slightly greater for the line drawings than for the printed words.

The most important result is the lack of reliable interactions involving the responses "true" and "false." The 20 msec difference between these two is not affected by the set of conditions used in this experiment, and this lends support to the methodological assertion that the nature of the S's task does not influence the relative speed with which spoken "true" and "false" activate a voice key. In light of this, there seems no reason to forgo the more natural responses "true" and "false" in favor of some artificial syllables which might be more phonetically and acoustically equivalent.

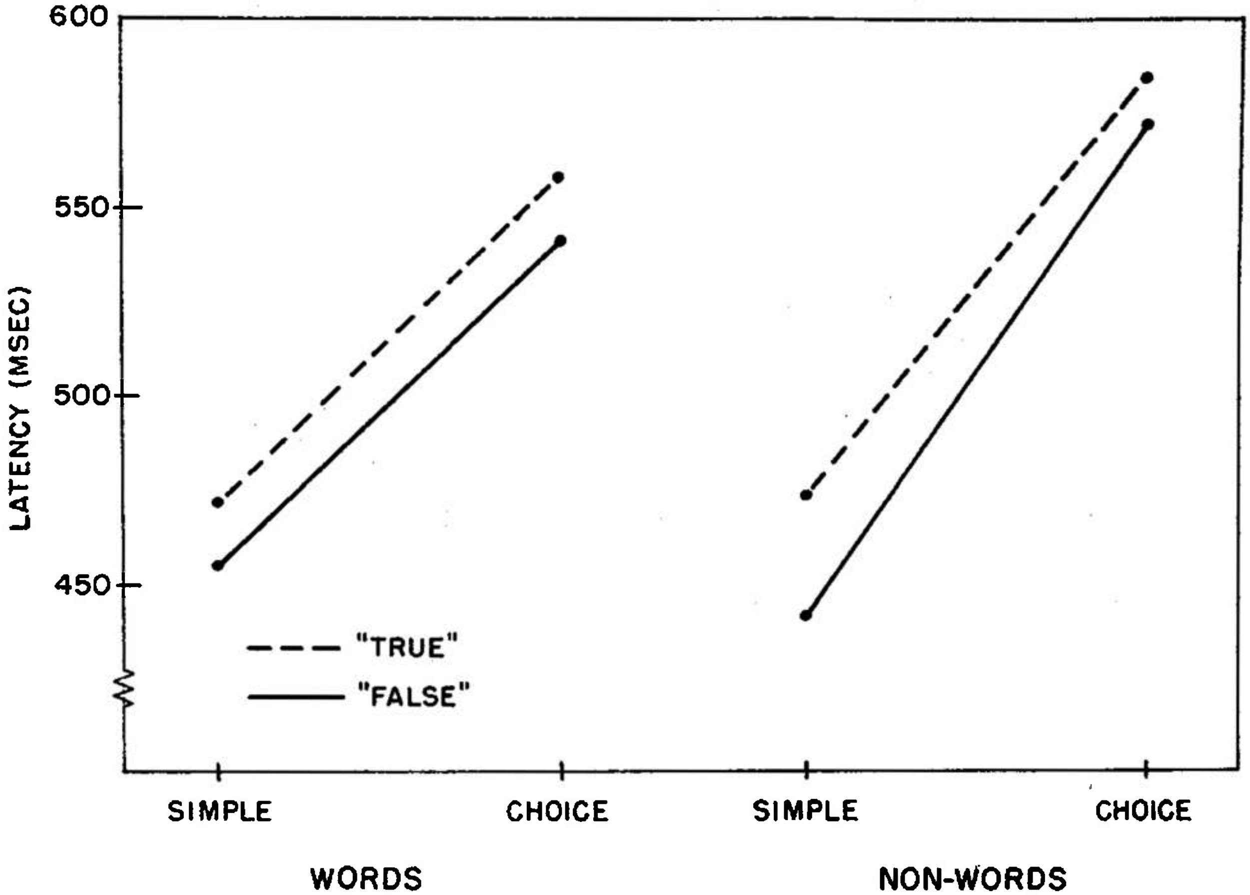

Fig. A-1. Mean reaction times for calibration experiment.

Table A-1. Summary of Analysis of Variance for Voice-Key Study

Source of Variation	Degrees of Freedom	Mean Square	*F*	*p*
True-False (T)	1	0.01157	14.94	<.005
Word-Symbol (W)	1	0.00479	4.25	<.05
T x W	1	0.00035	---	---
Choice-Simple (C)	1	0.34393	185.14	<.0005
T x C	1	0.00085	2.11	>.10
W x C	1	0.00961	6.04	<.05
T x W x C	1	0.00066	2.70	>.10
Subjects (S)	15	0.01207		
T x S	15	0.00077		
W x S	15	0.00113		
T x W x S	15	0.00042		
C x S	15	0.00186		
T x C x S	15	0.00040		
W x C x S	15	0.00159		
T x W x C x S	15	0.00025		

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13. ABSTRACT

Two experiments present further confirmatory evidence that the mental representation of the term "right" is simpler than that of "left." Experiment I was a simple extension of a series of earlier experiments, and showed that printing words top-to-bottom in displays did not eliminate the asymmetry in reaction times between "true" matches for "right" and for "left." This further confirms that the asymmetry depends upon mentally representing the two directions rather than upon visual scanning habits. Experiment II examined the verification of displays containing sentences and pictures. This more complex task induced greater variability among subjects, presumably because they adopted different strategies. Nonetheless, the confirmation of a strategy-free prediction provided additional support for the claim that "right" is easier to comprehend than "left."

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